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Secondary towns, agricultural prices, and intensification:

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Abstract

Urbanization is happening fast in the developing world and especially so in sub-Saharan Africa where growth rates of cities are among the highest in the world. While cities and, in particular, secondary towns, where most of the urban population in sub-Saharan Africa resides, affect agricultural practices in their rural hinterlands, this relationship is not well understood. To fill this gap, we develop a conceptual model to analyze how farmers' proximity to cities of different sizes affects agricultural prices and intensification of farming. We then test these predictions using large-scale survey data from producers of teff, a major staple crop in Ethiopia, relying on unique data on transport costs and road networks and implementing an array of econometric models. We find that agricultural price behavior and intensification is determined by proximity to a city and the type of city. While proximity to cities has a strong positive effect on agricultural output prices and on uptake of modern inputs and yields on farms, the effects on prices and intensification measures are lower for farmers in the rural hinterlands of secondary towns compared to primate cities.

Keywords: urbanization, cities, secondary towns, Ethiopia, sub-Saharan Africa, agricultural prices, intensification

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1. Introduction

Urbanization rates are quickly increasing in developing countries, with two-thirds of the world population anticipated to be living in cities by 2050 (UN Population Division 2014). Urbanization is considered an important long-term driver of economic development as it involves the structural transformation of the economy from being rural and agricultural-based towards one that is modern, urban, and industrial (Henderson and Wang 2005). Mostly through rural-urban migration, employment typically shifts from agricultural to more remunerative non-farm activities (Gollin et al. 2002). Moreover, agglomeration in primate cities (metropolization) can generate localized external economies of scale, technological innovations, industrial clustering or knowledge accumulation, and additional employment opportunities (Bloom et al. 2008; Henderson 2010). Urbanization also affects rural poverty through spillovers and economic linkages, such as remittances, upward pressure on rural wages, and rural non-farm income opportunities (Cali and Menon 2013; Dorosh and Thurlow 2013). Recent evidence has confirmed the positive correlation between urbanization rates and income per capita (Ravallion et al. 2007; Henderson 2010; Dorosh and Thurlow 2014), although establishing causality remains an important challenge when interpreting these empirical findings (Bloom et al. 2008).

In Africa, the share of the population that is urban, at 40 percent, is lower than in Latin America or Asia, but rapid increases in urbanization rates are anticipated over the next decades, resulting in a projected African urban population of 55 percent in 2050 (UN Population Division 2014). However, the process of urbanization in sub-Saharan Africa is argued as substantially different from the rest of the world. First, economic growth in African countries has been much slower compared to regions that have experienced similar changes in urbanization rates in the past decades (Bloom et al. 2008; Brückner 2012). Second, while industrialization and the creation of non-farm job opportunities have been the main drivers behind urbanization in Asia, African urbanization has occurred without industrialization. Instead urbanization resulted more from population pressure, natural resource exploitation, climate change, conflicts, and political or ethnical tensions (Bloom et al. 2008; Henderson et al. 2014; Gollin et al. 2016). As a consequence, there is renewed interest in policy research on how urbanization determines the structural process of transforming African economies (Brückner 2012; Henderson et al. 2013).

It is not only the aggregate rate of urbanization, but also its nature that affects the structural transformation process (Ferré et al. 2012; Christiaensen et al. 2016). Urbanization in Africa is characterized by a concentration of individuals in smaller urban centers. Only 10 percent of the African urban population resides in larger cities with between 5 million and 10 million inhabitants—the majority of the urban population lives in medium or small-sized cities of between 1 million and 5 million inhabitants (35 percent) or in small urban areas (55 percent) (UN Population Division 2014). Moreover, the populations in medium-sized cities has doubled in the last decade and is expected to grow by more than 30 percent in the next decade (UN Population Division 2014). As a consequence, the urban population in Africa is widely dispersed across cities of different sizes.

However, little is known about the mechanisms through which different sized cities affect livelihoods and welfare outcomes in their rural hinterlands. Migration to urban centers is associated with multiple spillover effects on the rural hinterland, and the growth of secondary towns therefore indirectly affects rural poverty levels. Especially consumption linkages between urban markets and rural producers seem important, primarily because higher food consumption and changing diet preferences in urban centers increase urban demand for rural agricultural products (Dorosh and Thurlow 2014; Tschirley et al. 2013; Reardon and Timmer 2014; Djurfeldt 2015). However, it remains unclear which type of urbanization (metropolization vs. more dispersed) is most beneficial for farmers in the rural hinterland.

A hierarchical pattern of settlements is believed to be more conducive to modernizing and commercializing subsistence agriculture (Brutzkus 1975).[1] As smaller cities are more closely located to the rural hinterland, the production and marketing linkages for agricultural products could be stronger because of lower transportation costs (Richards et al. 2016). Hence, the growth of secondary towns could benefit rural farmers – and other actors in agricultural value chains – because of improved market access and opportunities (Reardon 2016). Moreover, secondary towns provide rural farming households access to specialized services and facilities, input markets, and non-farm employment opportunities (Richards et al. 2016). Furthermore, as cultural ties and social networks might be stronger in smaller sized towns, these might be more effective in spreading and disseminating new ideas, agricultural innovations, and knowledge to farmers in the rural hinterland (Brutzkus 1975, Rondinelli 1983, Berdegué et al. 2015).

This paper contributes to this literature on secondary towns. First, we investigate the role of city size in the rural development process (Christiaensen et al. 2011, 2013; Christiaensen and Todo 2014; Dorosh and Thurlow 2013, 2014; Berdegué et al. 2015). Unlike the previous literature – which has mostly focused on poverty outcomes for migrants to the urban centers – we explore how urbanization patterns affect output prices and agricultural practices of farmers in the rural areas.

[1] In contrast, concentration in primate cities (e.g., national capitals) increases the demand for agricultural products, provides economies of scale for commerce at large central markets and concentrates the development of new agricultural technologies and innovations (Brutzkus 1975). Therefore, spread effects are hypothesized to be stronger for larger cities and for farmers located in the close vicinity of such cities (Benziger 1996).

We first develop a conceptual framework illustrating the effect of different sized towns on agricultural prices and intensification outcomes. Using a unique large-scale survey of staple crop (teff) producers in Ethiopia, our analysis and empirical results show that the size of the city matters for agricultural prices and intensification. Therefore, these results suggest the importance of differentiating city size when estimating the impact of urbanization on agricultural transformation, both in empirical regressions and in computable general equilibrium (CGE) models.

Second, this paper also relates to the literature that examines the effect of transportation costs on different aspects of economic growth in rural areas (Jacoby and Minten 2009; Gollin and Rogerson 2014; Jedwab and Moradi 2016, Storeygard 2016). We contribute to this literature by illustrating the important effects of transportation costs to primate and secondary cities on staple crop prices and production practices through different econometric methods, with a battery of controls of household and farm characteristics, as well as controls for self-selection and endogeneity of transportation costs, as roads might be constructed in areas with higher economic potential. We therefore apply an instrumental variable (IV) identification strategy. This introduces exogenous variation in transportation costs using Geographic Information System (GIS) datasets and natural path transportation cost estimates (Damania et al., 2016).

The paper is organized as follows. Section 2 provides background information on urbanization and teff production in Ethiopia. In Section 3, we outline a conceptual framework to assess the effect of cities on agricultural prices and intensification in the rural hinterland. Section 4 presents the data. In Section 5, we describe and execute different econometric models to compare prices and intensification decisions between farmers in the rural hinterland of Addis Ababa (the primate city) and secondary towns. We conclude in Section 6.

2. Urbanization patterns and teff production in Ethiopia

In Ethiopia, the population living in cities is expected to grow from 15.2 million in 2012 to 42.3 million by 2034, corresponding to an annual growth of 5.4 percent (World Bank 2015). Addis Ababa is by far the largest city in Ethiopia and about a quarter of the urban population in Ethiopia lives in the capital (Schmidt and Kedir 2009, CSA 2013b). At the same time, the expansion of smaller and medium sized cities is on the rise. This affects urban – rural relationships. For example, the percentage of the rural population less than 3 hours away from a city with a population of at least 50,000 has increased from 15 percent in 1997/1998 to 47 percent in 2010/11, partly driven by this city growth, but also by infrastructure improvements (Kedir et al. 2015).

In our analysis we focus on how these cities are related to teff prices and production in Ethiopia. In 2011, teff constituted 23 percent of the total grain crop area and 17 percent of total grain production in Ethiopia (CSA 2012). 29 percent of teff production is sold, which is a relatively high share compared to other cereals, such as wheat and maize (at 20 percent and 11 percent, respectively). Hence, teff has a higher commercial surplus, and is often considered a cash crop for farmers engaged in its production (Minten et al. 2015, 2016). Teff is more readily eaten in urban than rural areas. In urban areas, teff has a high share (23 percent) of per capita consumption in total food consumption (Berhane et al. 2011). In Addis Ababa, teff accounts for almost half of total cereal expenditure, and teff is consumed more by richer and urban households. The income elasticity of demand for teff in urban areas is around 1.1 (Berhane et al. 2011). Because cities and urban incomes are growing quickly, the demand for teff is expanding and expected to further increase (Minten et al. 2015, 2016).

As teff is a major staple crop and source of income for farmers in rural areas and is an important food for urban consumers, it is therefore especially relevant for Ethiopian policy makers because of its implication on food security and income. Teff production and consumption is mainly restricted to Ethiopia, and there is practically no international trade of teff. The closed economic setting of teff in Ethiopia, and as a consequence, teff prices – as well as other intensification outcomes – are not directly determined by international prices. Teff is therefore an interesting case to study domestic urbanization induced agricultural transformation.

3. Urbanization and agricultural intensification: A conceptual framework

(a) One city model

Consider an agricultural commodity which is produced by a representative farmer in a rural area and sold in a city (City 1) where all the consumers live. Define d as the distance from the farm to the city.[2] The farmer uses input L to produce agricultural output Y. The production function is

$$Y = A(d) * f(L) \tag{1}$$

where $f(L)$ has standard concave properties of $f_L > 0$ and $f_{LL} < 0$. $A(d)$ is a factor neutral productivity shifter – which is assumed to capture the direct productivity effect of being close to the city – with $\frac{\partial A(d)}{\partial d} < 0$.[3] The effective price the farmer receives for his output is a function of the price in the city and the distance to the city (De Janvry et al. 1991; Minten and Kyle 1999). The

[2] The farmer's decision to sell output at a market may also depend on market distance (Key et al. 2000; Renkow et al. 2004; Poulton et al. 2006; Barrett 2008). We do not explicitly model the market participation decision, and instead assume that the farmer sells output at the market.

[3] The productivity effect comes from better access to infrastructure and services, extension and information, improved technologies and better networks for farmers closer to cities (Stifel and Minten 2008, 2017; Josephson et al. 2014).

price of the agricultural commodity in the urban market of City 1 is p^u. Define $\mu(d)$ as the per unit cost of transportation to the city with $\frac{\partial \mu(d)}{\partial d} > 0$. The effective output price for the farmer, *p*, is then

$$p = p^u - \mu(d) \tag{2}$$

Distance to the city may also affect the costs of inputs for farmers. As a general specification, we can write the cost per unit of input t $\mathrm{r}_L = \mathrm{r}_L(\mathrm{r}_L{}^u, d)$, with $\mathrm{r}_L{}^u$ the price of input L in the urban market. The impact of d on r_L ($\frac{\partial \mathrm{r}_L}{\partial d}$) is likely to depend on the nature of the input.[4] We focus here on the use of modern inputs, i.e., chemical fertilizer and improved seeds, as agricultural intensification usually involves the increased uptake of these inputs (see Vandercasteelen et al. (2016) for an analysis of land and labor use). The nominal prices of fertilizer and improved seeds are unlikely to change over distance in Ethiopia, as they are sold by state-controlled cooperatives at fixed prices in each village (Rashid et al. 2013). However, while the nominal prices may be the same for all cooperatives, Minten et al. (2013) find that the transaction costs of obtaining fertilizer and improved seeds are much higher in remote areas.[5] If we interpret r_L as the per unit opportunity cost of acquiring fertilizer and seeds, then $\frac{\partial \mathrm{r}_L}{\partial d} > 0$.

The farmer maximizes the following profit function

$$\max_L \Pi = max(p * Y - r_L * L) \tag{3}$$

[4] If the farmer buys his inputs in the city and has to transport this to the farm, his input costs will increase with distance to the city. However, if the city competes with the farm as a potential alternative use for the input, there will be opposing effects of distance on the input price because of increased competition and at the same time lower transport costs. This is particularly relevant for labor input. If the alternative employment for labor is employment in the city, the price of labor will be lower the further away from the city.

[5] One factor is the uncertainty of suppliers; hence farmers have to go multiple times to the cooperative to acquire their inputs. Minten et al. (2013) show a significant positive effect of distance to a market town on the time it takes to acquire inputs.

which yields the input demand function:

$$\Pi_L: p(d) * [A(d) * f_L(L^*)] - \mathrm{r}_L(d) = 0 \tag{4}$$

This first order condition (FOC) defines the optimal demand for input L^* as a function of the distance to the city (d):

$$\frac{\partial L^*}{\partial d} = -\frac{\partial \mathrm{r}_L}{\partial d} + A * f_L * \theta^L * \frac{\partial p}{\partial d} + p * f_L * \theta^L * \frac{\partial A}{\partial d} \tag{5}$$

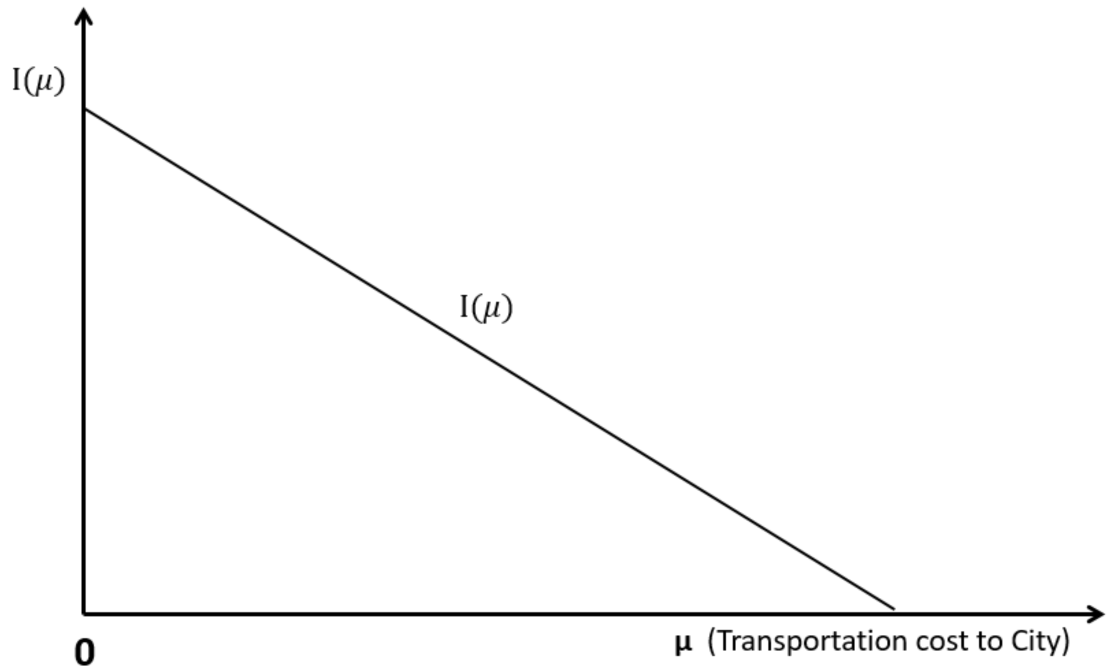
where $\theta^L = 1/\,[\,1 - p * A * f_{LL}\,]$. Equation 5 shows that there are three effects of distance from the city on the input used on a farm. The first term captures the own price effect of the input – in the case of modern seeds and chemical fertilizer, this is either zero or negative. The second term and third term, respectively, capture the output price effect and the impact of declining productivity with distance. With θ^L positive, the output price effect (second term) and the productivity effect (third term) are definitely negative: a fall in the output price and in productivity both reduces the demand for inputs. Hence, our simple model predicts that the effect of distance on the uptake of improved seeds and chemical fertilizer (or other modern inputs) is likely to be negative.[6]

Figure 3.1 presents a very simple graphical illustration of our "one-city-model". City 1 ("the capital") is located at point 0 on the horizontal axis. All farmers are located to the right of City 1 on a single distance line, with distance represented by transportation costs μ. The vertical axis measures the size of I (which is an indicator) that captures key variables of interest (prices and the use of modern inputs). Our model predicts that all these variables (prices and modern input use)

[6] For the case of other inputs (labor or land) in the one input case, or for the case of multiple inputs (there may be additional substitution or complementarity effects), see Vandercasteelen et al. (2016).

will decline with distance to the city, represented by a declining *I(μ)* function. Obviously the shape of the function (linear or not), its slope, and the height of the intercept will depend on the specific variable (prices and various inputs). However, as we will show further, for illustrative purposes this simplified general function is a useful representation when we add complexities, such as by adding more cities to the model, and when we feed empirical data into the model at a later stage.

Figure 3.1: Impact of proximity to City 1 on prices and modern input use (I)



(b) Secondary town model

We now extend this framework by analyzing how the presence of more (secondary) towns changes these relationships. With more cities, we can define an I-function for each city *i* which represent how prices and modern input use will change with distance from city i, i.e., $I_i(\mu_i)$ with μ_i transport costs to City *i*.

A key question relates to differences in the shape of the I-functions for different cities. In terms of the linear I-function of Figure 3.1, this means whether the slopes of the I-functions are the same and whether they have the same maximum. One can imagine different reasons why neither the maximum value nor the slope should be identical for different cities. For example, in the case of agricultural output prices, it may be that the price in (smaller) secondary towns is lower than the price in the capital, since demand may be lower in smaller cities, transaction costs may be lower, or markets may not be as well integrated. In this case, the maximum value Ii(0) would differ. It is also possible that per unit costs of transport are higher closer to smaller secondary towns because of poorer road infrastructure or because of less competition in the transport sector (possibly linked to thinner markets). In this case the slope of the Ii(μi) would be steeper. These are essentially empirical issues. For our conceptual framework we will illustrate the impacts under different assumptions.

Consider first the case where there is one additional (secondary) city (City 2) with the same slope of the I-function as City 1 but a lower maximum *I* value ($I_1(0) > I_2(0)$). This case is illustrated by Figure 3.2. Farmers are located to the right of the capital (City 1) and at both sides of the secondary town (City 2). The black line represents the I_1 function, which is the impact of City 1 on prices or modern input use, and the gray line represents the I_2 function, which is the impact of City 2. Farmers which are closer (in terms of transport costs) to City 1 than μ_1* will be dominated by the influence of City 1 (as $I_1(\mu_1) > I_2(\mu_2)$). Farmers which are further away from City 1 (to the right of μ_1* on the vertical axis) will be influenced mostly by City 2, as the proximity to secondary City 2 will determine their prices and modern input use, rather than distance to the capital city (as $I_1(\mu_1) < I_2(\mu_2)$ for these farmers). It is easy to see that the lower $I_2(0)$, the smaller the impact of the secondary city (and vice versa). In fact, if $I_2(0)$ would be less than $I_1(\mu_1^2)$, there would be no effect of the secondary city. Similarly, the impact of the secondary city would be smaller if the slope of the I_2 function is steeper, as higher transport costs would reduce its region of impact (and vice versa).

Figure 3.2: Impact of capital City 1 and secondary City 2 on prices and modern input use (I)

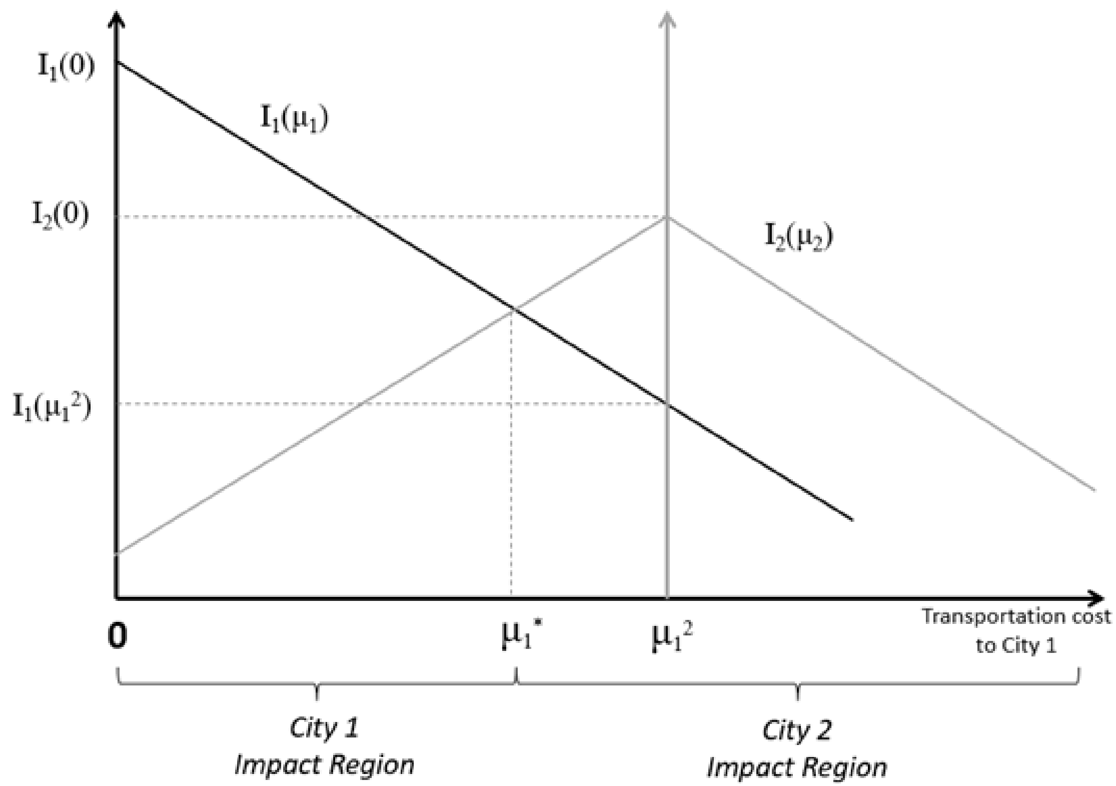
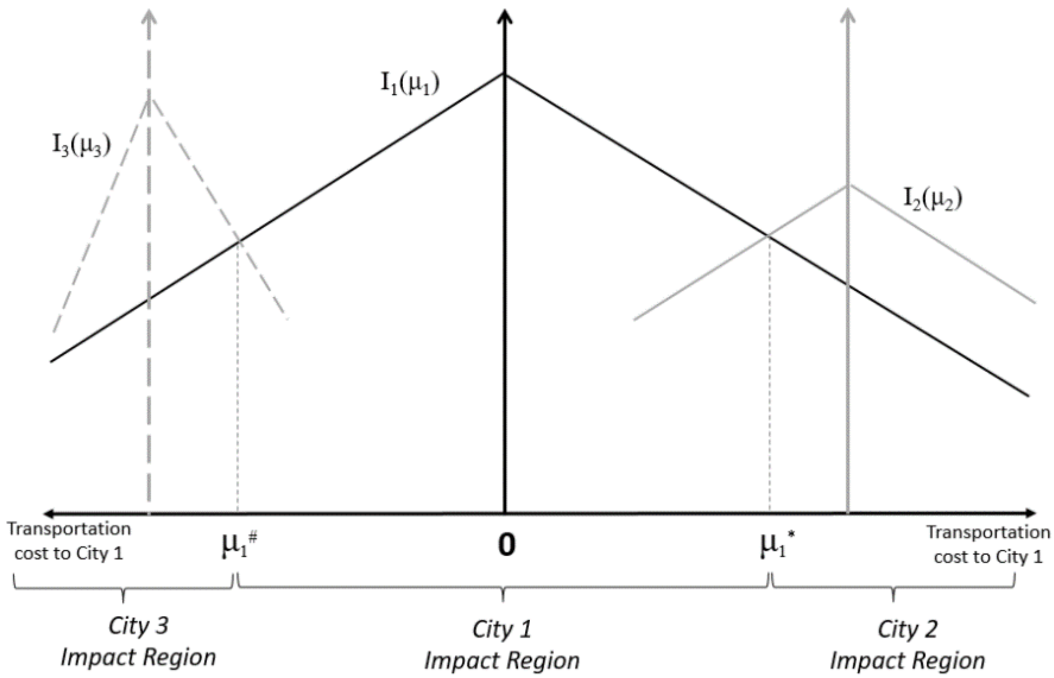


Figure 3.3 presents a more complex example where the capital City 1 is in the center and there are secondary cities on both sides. The "impact region" of City 1 is now the transport costs region starting from $\mu_1\#$ to the left of City 1 to μ_1* to the right. All farmers who are within this distance are influenced by City 1 in the prices they set and their input use. Farmers who are further away are influenced by secondary cities, either City 2 on the right hand side (farmers for which $\mu_1 > \mu_1*$) or by City 3 on the left hand side (farmers for which $\mu_1 > \mu_1^{\#}$).

Figure 3.3: Impact of capital City 1 and secondary Cities 2 and 3 on prices and modern input use (I)



This simple conceptual model suggests hypotheses on how the presence of secondary towns affects agricultural prices and the use of modern inputs by farmers. If there are no secondary town effects, we would find a continuously declining relationship between prices or modern input use and transport costs from the primate city. If the presence of the secondary town does influence prices and agricultural intensification measures, we expect to see the decline of the primate city's impact disrupted by increasing prices and input use due to impact of secondary cities, as illustrated in Figures 3.2 and 3.3. In the following sections, we will first simulate the predicted impacts of our conceptual model on output prices using actual transport cost data, and compare these simulated results with actual observations. Later, we will estimate the impact of the secondary cities using econometric techniques.

4. Methodology

(a) Data and descriptive statistics

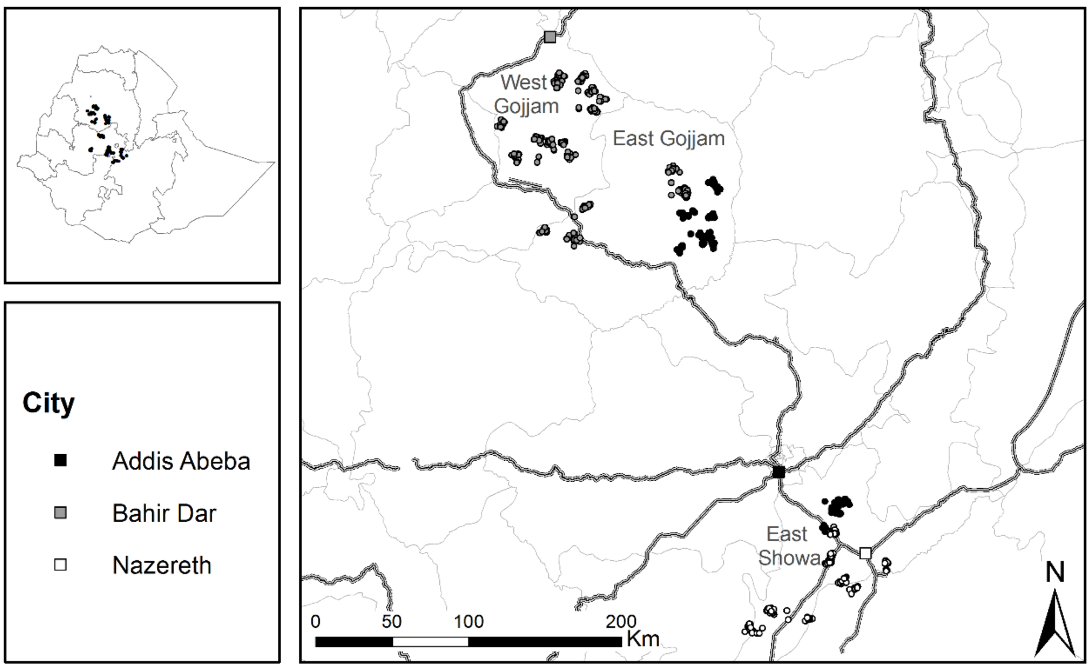
We use data on teff producers from Ethiopia collected in November and December2012. Appendix I explains the sampling procedure that was used. We focus on the zones in this dataset which contain secondary towns of substantial size, at least in terms of population numbers, that function as an important regional hub or consumption center of teff in Ethiopia. Nazareth (or Adama) is located in East Showa (southeast of Addis Ababa) and is an important hub from which to export teff to the regional capitals in the east (Dire Dawa or Harar) and the south (Hawassa) of Ethiopia. Bahir Dar is located in West Gojjam (northwest of Addis Ababa) and is an important hub for transporting teff to the cities of Mekelle and Gonder in the north. We also assume that (some) farmers in East Gojjam might be affected by Bahir Dar, as there is no secondary town of substantial population numbers nearby. As a consequence, the empirical analysis will focus on the 720 farmers who are located in the three zones of West Gojjam, East Gojjam and East Showa.[7]

The map in Figure 4.1 gives an overview of the survey areas and the location of the farmers that were interviewed. It is shown that we have data on farmers who are more or less located along a straight line from Bahir Dar to Nazareth, passing Addis Ababa and connected by one of the most

[7] Nazareth is projected to become the second largest city in Ethiopia in 2016 (342,940 inhabitants), while Bahir Dar will be the sixth largest city with 297,794 inhabitants. Based on international standards, these cities would be classified as “Urban areas smaller than 500 000” (UN Population Division 2014). There is no sizable secondary town in the vicinity of surveyed farmers in South West Showa (the fourth zone in our dataset). The largest city in West Showa (the fifth zone) is Ambo, which has less than 100,000 inhabitants. Moreover, the surveyed farmers in that zone are not located along the route from Ambo to Addis Ababa.

important national roads in Ethiopia. To make the link with the conceptual model, we consider Addis Ababa to be at the origin, while farmers in East and West Gojjam are located on the left of Addis Ababa and farmers in East Showa are located on the right of the capital. Hence, the data suits the general specification of the two-dimensional model of farmers located on the straight line that connects three cities, with the primate city, Addis Ababa, in the middle.[8]

Figure 4.1: Overview of the survey area with major roads and the three studied cities.



Our main independent variables of interest are the cities where farmers' teff is sold and farmers' distances to that city. We consider these three cities - Addis Ababa, Nazareth, and Bahir Dar - as the major regional teff markets. To identify – for each farmer – the most likely city that

[8] The geographical location of the secondary towns in space determines how far the influence of the secondary town on the farmers reaches, relative to farmers' distance from Addis Ababa. For example, most of the farmers in West and East Gojjam – with a few exceptions – are located between Bahir Dar and Addis Ababa. For these farmers, the effect of the secondary town is likely to be more visible as both cities are located quite far from each other. In contrast, Addis Ababa and Nazareth are located close by, and there are farmers located on both sides of Nazareth. Hence, the influence of each city is determined by the prices of teff in each city, the distance of each farmer with respect to the capital and secondary town, and transportation cost functions for each city. Defining this rural hinterland corresponds with determining – for each farmer – the most profitable city for which to produce.

the teff each produces is shipped to for market, we use the assumption that traders will ship teff from their farm to the city to achieve the maximum net price of teff. This net price is the difference between the market price in the city and the total cost incurred by traders of shipping teff to the city, i.e., the function $P_f=P_1-\mu$. The net price is calculated for all three cities, and we select the city that offers the maximum price for each farmer. This city will then be used as the most likely destination of teff, and is either Addis Ababa or one of the secondary towns.[9] For example, for some farmers in the region of West Gojjam, the end destination of teff will be Bahir Dar, because this city maximizes their teff prices; while for some farmers in East Showa the end destination is Nazareth.

Table 4.1 provides an overview of the prices, transport cost (from the trader town to the city), net prices, and the number of farmers in our survey who supply to each of the three cities. Table 4.1 also shows the descriptive statistics on the household head and farm characteristics of these teff farmers. The different colors for farmers in Figure 4.1 correspond to the city to which they are the most likely to ship their teff.

Table 4.1: End destination for teff produced by study farmers and characteristics of farmers by that end destination

	End destination for teff produced by farmers		
Variable	**Addis Ababa**	**Bahir Dar**	**Nazaret**
Zone	*Addis Ababa*	*East Gojjam*	*East*
Teff price in city (ETB/quintal)	1,382	1,226	1,344
Transport cost (ETB/quintal)	56	96	84
Price net of transport (ETB/quintal)	822	270	504
Number of farmers	177	359	184
Farmers (%)	25	50	25
	Farmer characteristics by end		

[9] For each farmer, the price function P_f is calculated for Addis Ababa, Bahir Dar, and Nazareth. If the net price that the farmer would receive from shipping teff to Addis Ababa is higher than the net price in Bahir Dar, then this farmer is assigned to Addis Ababa.

Variable	**Addis Ababa**	**Secondary Town**
Age of head (years)	44	46*
Male head of household (%)	95	95
Head has at least one year of education (%)	51	52
Head is of Oromo ethnic group (%)	26	28
Household size (number)	6	6*
Households owning mobile phone (%)	35	25
Farm assets, ln ETB	6	7
Travel time to nearest dry weather road (minutes)	29	35
Travel time to nearest all weather road (minutes)	59	67
Household took loan last year (%)	35	31
Household is member of agricultural cooperative (%)	65	65

Note: The asterisk shown in the second panel indicates whether the comparison of the means of the two groups of farmers yielded a significant difference at the 10% level. Number of observations is 720.

Among the right-hand explanatory variables, we use the transportation costs that farmers face when shipping their teff to a city. Such an indicator is assumed to be a better measurement of market proximity than physical distance or travel times (Chamberlin and Jayne 2013). In practice, this transportation cost is calculated as the cost of transporting one quintal (100 kg) of teff from the farm to the city where the teff is most likely to end up. This cost of shipping teff is the combination of two separate costs. First, we use farmers' self-reported cost incurred in travelling with their harvested teff from their farm to the local market. Second, in these local markets, traders purchase teff and ship it to one of these three cities. As the teff is shipped from a local market to a city by motorized trucks, we use a spatial network analysis function in GIS to calculate the 'truck cost' for the second trip. The exact details on the calculations of transport costs are explained in Appendix II. These results were calibrated with data on transportation costs from community surveys and from a truck driver survey implemented at the same time as the teff producer survey. Table 4.2 provides an overview of the transportation cost measures and other variables of interest. On average, it costs 47 ETB per quintal to ship teff from the farm to the city, of which the cost from farm to local market contributes about 13 ETB per quintal and the truck trip from local market to the city costs on average 34 ETB per quintal.

On top of prices and costs, different intensification outcomes in teff production are also reported in Table 4.2 for the selected 720 farmers. These outcomes are input (fertilizer and improved seeds) application and teff land productivity (kg per ha).[10] Such modern inputs are promoted by the government to stimulate agricultural production in the country (Bachewe et al. 2015). During the household survey, detailed data on production practices were gathered, as well as on inputs applied and on teff output for each teff plot level. This was then averaged over all plots cultivated by the household. Further, data on teff prices (ETB per quintal) were collected in the household survey (teff transaction section) which contained information on quantities sold, prices received, main place of sales, and the buyer in each teff sales transaction during the last production season. Monthly village level wage data were further aggregated to yearly averages (in ETB per day).

Table 4.2: Explanatory variables, descriptive statistics

Variable	Unit	Data source	Mean	Median	SD
		Prices			
Price of teff	ETB/quintal	Teff transaction level	1,035	1,027	116
Wage rates	ETB/day	Community level	37	38	12
Land rental rate	ETB/ha	Community level	4,697	4,709	130
Price of DAP	ETB/quintal	Community level	1,384	1,411	115
Price of Urea	ETB/quintal	Community level	1,128	1,167	120
		Agricultural inputs			
Use of DAP	kg/ha	Farmer plot level	101	96	78
Use of Urea	kg/ha	Farmer plot level	71	51	76
Use of improved seeds	kg/ha	Farmer plot level	13	0	22
		Intensification outcomes			

[10] All the intensification outcomes are trimmed (replacing the top and bottom 1 percent of non-missing values by village average) to control for potential outliers. Results are similar if the data is not trimmed.

Teff land productivity	kg/ha	Farmer plot level	1,231	1,179	671
Transportation cost measurements					
Cost from farm to local market	ETB/quintal	Teff transaction level	14	14	8
Truck cost from local market to city	ETB/quintal	Trader and truck survey, road network	33	33	19
Total transportation cost	ETB/quintal	Donkey and truck cost	47	47	16
Natural path travel time	Hours	GIS analysis	17	15	10

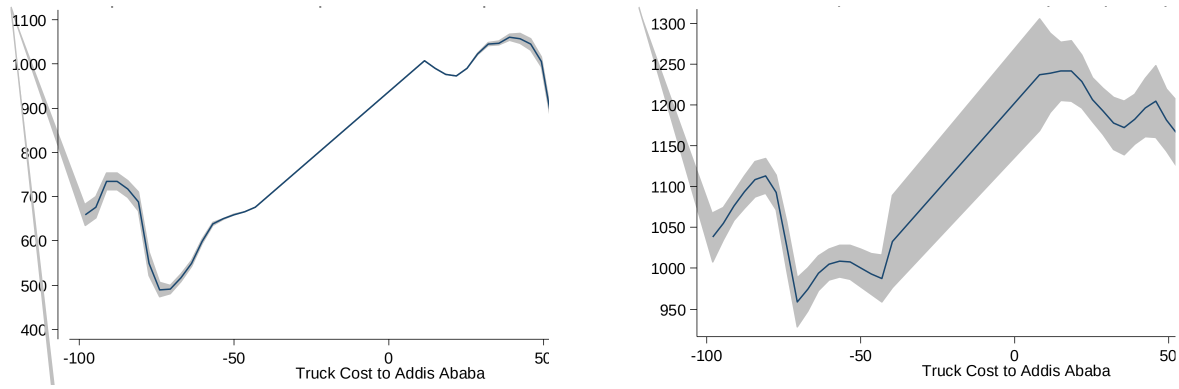
Note: Number of observations in each model is 720. ‘SD’ is the standard deviation.

(b) Simulation results and observed teff prices

The theoretical model shows that if secondary towns are important for agricultural prices and modern input use, there should be non-linearities in the relationship between these variables and the distance to Addis Ababa. As a first step, we simulate the model predictions for teff prices since we can use data on retail prices for teff in the markets of Addis Ababa, Nazareth, and Bahir Dar from the Central Statistical Agency during the survey period (CSA 2013a). Using these prices as a benchmark, Figure 4.2 plots the simulated (left graph) prices and actual prices, as reported by farmers (right graph), against the truck cost to ship teff to Addis Ababa. To ease interpretation, we posit farmers in East and West Gojjam on the left of the origin by assigning them negative transportation costs. This allows us to compare the model predictions, illustrated in Figure 3.3, with the empirical relationship of prices and proximity to the capital Addis Ababa.[11]

Figure 4.2: Predicted (left graph) and observed (right graph) teff prices (y-axis) over transport cost to Addis Ababa (x-axis), ETB/quintal

[11] Given that the truck cost is calculated using the road segments, this measurement takes into account differences in road quality and thus transaction costs. Therefore, the relationship between prices and proximity to Addis Ababa might follow a pattern which is more in line with Figure 4.2.



Note: The solid lines represent local polynomial smoothing estimates of transportation cost (x-axis) on output prices (y-axis). The shaded area is the 95% confidence interval.

The left graph in Figure 4.2 illustrates how the distance to Addis Ababa affects the teff price net of transport cost as simulated using the model in our conceptual framework. In the right graph in Figure 4.2, the empirical relationship between reported teff prices and distance to Addis Ababa is presented. In general, we observe that the predicted prices and prices reported by farmers follow a similar trend over transportation costs to Addis. The teff price received by farmers in East and West Gojjam (on the negative part of the x-axis) decreases with distance up to a certain transport cost, before the effect of the secondary city, Bahir Dar, appears. At this point, i.e., μ_1 in Figure 3.3, the net price that farmers receive in Bahir Dar becomes higher than the net price in Addis Ababa and teff will be shipped to Bahir Dar. The teff price for farmers with higher transport cost will be positively affected by the distance to Addis Ababa. This negative relationship with distance to Addis Ababa therefore shows a kink, where the secondary town is located, and afterwards prices are again negatively related to distance to Addis Ababa. The net price received by farmers on the right of Addis Ababa shows also a non-linear kinked pattern. With low transport costs, net teff prices decrease with distance up to a certain transport cost where prices become more or less flat, i.e. at the location of Nazareth. For farmers located further than Nazareth, prices are again strongly and negatively related to distance from Addis Ababa. Hence, the fact that there are non-linearities in both the left and right price relationships with respect to distance to Addis Ababa in the graphs, suggests that secondary towns indeed affect teff prices.

5. Regression Analysis

(a) Empirical Specification

To measure the relationship between types of cities and proximity to a city on the one hand, and agricultural prices and intensification on the other hand, we estimate the following regression model:

$$\mathrm{Y}_i = \alpha_\mathrm{y} + \beta_\mathrm{y} * \mathrm{T}_i + \gamma_\mathrm{y} * \mathrm{S}_i + \mathrm{X}_i + \mathrm{Z}_i + \varepsilon_{\mathrm{i,y}} \quad (6)$$

where Y_i is the outcome variable of interest, T_i is transport cost from the farm to the city where the teff is shipped to, S_i indicates whether a farmer is a *secondary town farmer* compared to an *Addis Ababa farmer* (further, we will refer to farmers who ship their teff to Addis Ababa as 'Addis Ababa farmers' and those who ship their teff to a secondary town as 'secondary town farmers'), Z_i are zonal fixed effects, $\varepsilon_{\mathrm{i,y}}$ is the idiosyncratic error term of outcome Y_i, X_i a matrix of household controls and contains (i) age, gender, ethnicity, and education of the household head, (ii) household's membership in an agricultural cooperative, assets value, land holdings, ownership of mobile phone/radio and member size; and (iii) agro-ecological conditions (altitude, the share of brown or black soils, and the share of flat – versus sloped – land). Moreover, prices of outputs and inputs are additionally included for the models where intensification measures are the dependent variables.[12] Standard errors are clustered at the village level.

There are two main estimation issues for these empirical estimates. First, there might be selection bias because of systematic differences between Addis Ababa farmers and those supplying secondary towns. We therefore apply a double robust regression approach to control for observable selection issues. First, we estimate the probability to be a secondary town farmer based on household characteristics (age, gender, education, ethnicity, household size, number of children), asset ownership (radio, TV, mobile phone, wealth index), value of agricultural assets, proxy for teff farming ability, and the total cultivated teff land owned by the household.[13] From this probit model we then estimate the propensity score. The results of this regression are reported in Table 5.1. Second, we use the inverse of the propensity score to weight our regressions in the subsequent analysis to control for potential selection biases in S_i. We further also include regional fixed effects as an additional control for farmers who are in the same geographical zone.

Table 5.1: Probit model results for estimation of propensity score of being a farmer supplying teff to a secondary town and not Addis Ababa

	Secondary town farmer	
Explanatory variables	**Coefficient**	**Standard Error**
Age of head (years)	-0.002	0.005
Male head of household (yes=1)	-0.026	0.247
Educated head with at least one year of schooling (yes=1)	0.162	0.111
Head is from Oromia (yes=1)	0.085	0.419
Household size (persons)	0.011	0.066
Children in the household (number)	0.007	0.057

[12] To do so, the reported land rental rates, input and teff output prices are regressed on the parcel-level and transaction-level determinants of prices respectively using a fixed effect model. From these panel estimations, the predicted values of the land rental, output and input price are calculated for each farmer and are used as independent variables in the implemented regressions.

[13] The wealth index is constructed using a Principal Component Analysis on different housing assets. The farming ability in teff is proxied by the household fixed effects from estimating a teff production function.

Household owns a radio (yes=1)	0.180	0.184
Household owns a TV (yes=1)	-0.884***	0.298
Household owns a mobile phone (yes=1)	-0.348*	0.198
Farm assets value (ln ETB)	0.155*	0.091
Wealth index (PCA of housing assets)	0.240	0.219
Farming ability *	-0.686***	0.201
Land owned (ha)	0.199***	0.072
Constant	-1.606	1.511

Note: Number of observations is 720. Standard errors are clustered at village level and reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1. * For definition of the 'Farming Ability' variable, see Vandercasteelen et al. (2016).

Second, it can be argued that roads (transport infrastructure) are not placed randomly in space and are denser in areas with higher economic potential. Hence, our measure of transportation cost could be endogenous. We therefore apply an instrumental variable (IV) approach to address this concern. The implemented approach follows the methodology pioneered by Damania et al. (2016). We instrument transportation costs with a 'natural path' measure, which is the time (in hours) it takes to walk from a production area to the market place, in the absence of any transportation infrastructure. This measure takes into account the effect of geography, i.e., travel speed adjusted by slope, and does not follow the potentially endogenous road networks in areas with higher economic potential. Instead, it provides the most efficient, i.e., the least costly in terms of hiking time, path that farmers would take if they had to transport their teff on foot.

Equation 6 is estimated both using Ordinary Least Squares (OLS) and Two-Stage Least Squares (2SLS), where we instrument transport cost with the 'natural path' measure to control for potential endogenous effects. The results of the first stage regression for the 2SLS method are reported in Table 5.2. It shows that an additional hour of walking from the farm to the city where the teff is sold increases – all else being equal – transportation costs by 1.5 ETB per quintal. The bottom of Table 5.2 reports the results of first-stage tests for weak instruments. The different R-squared measures (normal, partial, and adjusted) indicate a strong correlation between the natural path measure and transportation cost. The F-statistic is significantly different from zero, large in magnitude, and is therefore well above the critical values suggested by Stock and Yogo (2005). This suggests that the natural path variable is sufficiently strongly correlated to the endogenous transportation cost measure to make it a valid instrument.

Table 5.2: First stage of Two-Stage Least Squares (2SLS) regression

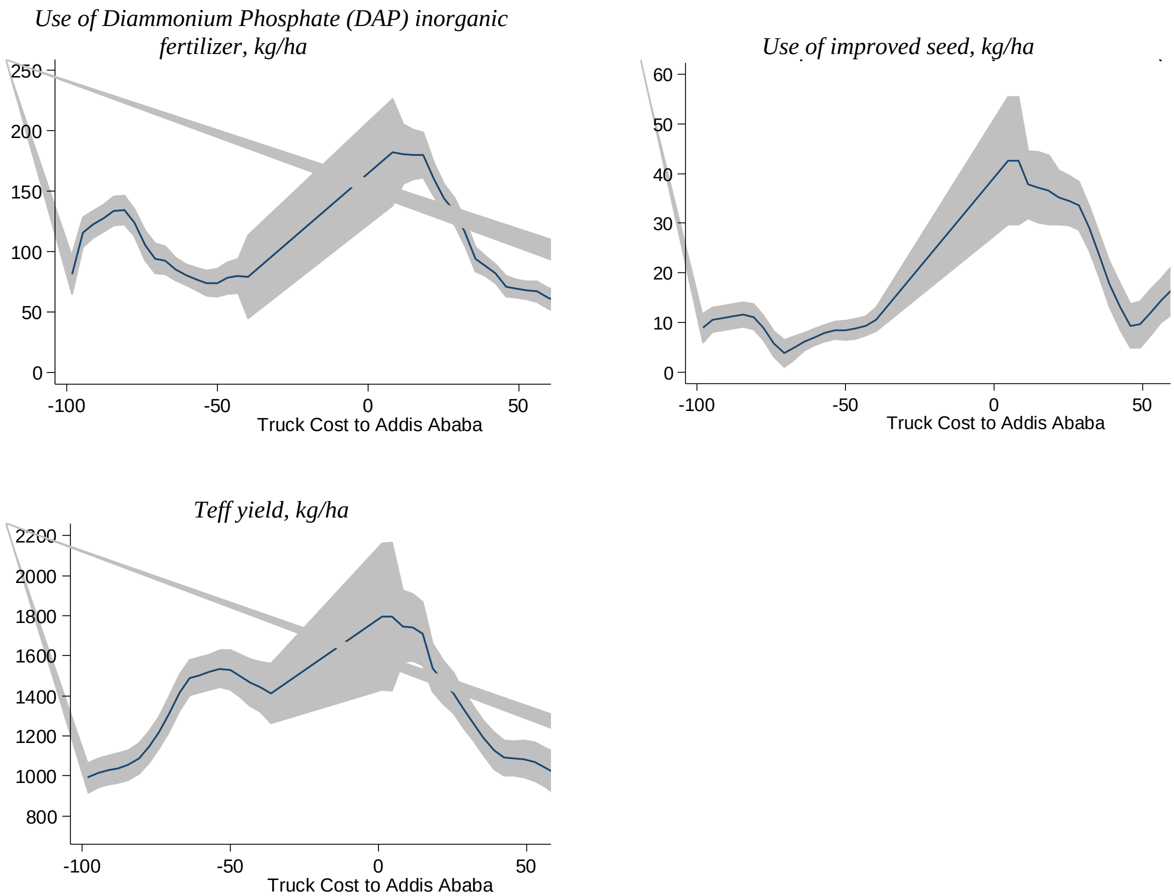
	Transportation Cost (ETB/quintal)	
Explanatory variables	**Coefficient**	**Standard Error**
Natural path travel time	1.56***	0.09
Secondary town	2.98*	1.54
Teff price	-11.20***	2.44
Wage	1.41	1.65
Land rental rate	-53.70***	17.80
Price of DAP	-3.30	7.97
Price of Urea	20.50***	6.13
Age of head	-0.13***	0.04
Male head of household	-2.95	2.04
Educated head with at least one year of schooling	-0.24	0.90
Head is from Oromia	0.05	1.86
Farm assets value	0.18	0.93
Household is member of agricultural cooperative	-0.63***	0.22
Household size	-0.08	0.21
Land owned by the household	1.30***	0.37
Household owns a mobile phone	2.00	1.22
Household owns a radio	1.46	1.19
Elevation	-0.01***	0.002
Share of black and brown soils	-2.15**	1.02
Share of flat soils	-3.02**	1.24
Constant	447***	149
Zone fixed effects	Yes	
Observations	720	
R-squared	0.64	
Adjusted R-squared	0.63	
Shea's partial R-squared	0.27	
Robust F(1,697)	280.62***	

Note: Results of first stage of Two-Stage Least Squares (2SLS) regression where transport cost is instrumented with a 'natural path' measure of time to walk from production area to market place. Number of observations is 720. Standard errors are clustered at village level and reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1.

(b) Regression results

To start our regression analysis, we first present non-parametric regression results on land intensification measures. In Figure 5.1, we plot three measures of intensification as a function of transport cost to Addis Ababa – fertilizer use, improved seed use, and teff yields, all of which change with transportation costs. We see that the use of both inputs does not linearly decrease over space, and is therefore seemingly affected by the presence of the secondary towns Bahir Dar and Nazareth. Teff yields also show non-linearities at both sides of the capital city, but the effect of the secondary towns, i.e., the kinks in the graphs, are less clear than for teff prices and improved seed usage. In any case, these graphs tend to suggest that secondary towns do affect intensification in rural hinterlands in Ethiopia.

Figure 5.1: Use of DAP inorganic fertilizer (kg/ha) (upper left graph); use of improved seed (kg/ha) (upper right graph); and teff yields (kg/ha) (lower left graph) as a function of transport cost to Addis Ababa



Note: The solid lines represent local polynomial smoothing estimates of transportation cost (x-axis) on different teff outcomes (y-axis). The shaded area corresponds with the 95 percent confidence intervals.

The effect of cities and distance is further evaluated through a multi-variate regression analysis by using the models explained in Section 5.1. In the first specification (column S1 in Table 5.3), we estimate a reduced form of Equation 6 with only zone effects as control variables. In the second specification (column S2), we control for household characteristics and prices for land intensification measures. The first and second panel report the results from the OLS estimation and the 2SLS estimation (where transport costs are instrumented), respectively. To improve readability of the results, we only report the regression coefficients of the secondary town dummy and transport cost.

Table 5.3: Transportation cost, cities, and teff intensification.

	Price of teff (ETB/quintal)		Improved seed (kg/ha)		Fertilizer use (kg/ha)		Yield (kg/ha)	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
OLS regression								
Transportation cost to the city, ETB/quintal	-3.97***	-3.38***	-0.44***	-0.42***	-3.35***	-2.76***	-17.33***	-12.72***
	(0.66)	(0.70)	(0.13)	(0.12)	(0.47)	(0.43)	(2.72)	(2.61)
Secondary town	-100.31***	-79.46***	-11.84***	-13.11***	-126.91***	-86.43***	-372.93***	-247.42**
	(20.96)	(18.90)	(3.12)	(2.99)	(20.73)	(19.33)	(129.92)	(114.46)
Constant	7,166.46***	6,797.43***	38.97***	-308.40	441.48***	-577.23	2,774.70***	-27,770.27***
	(42.64)	(174.17)	(8.26)	(259.52)	(27.11)	(1,484.53)	(199.40)	(9,125.44)
Prices	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Zone fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.248	0.297	0.209	0.325	0.306	0.441	0.215	0.286
2SLS regression								
Transportation cost to the city, ETB/quintal	-4.85***	-4.74***	-0.59***	-0.66***	-3.90***	-3.52***	-17.82***	-12.54**
	(0.77)	(0.85)	(0.19)	(0.19)	(0.65)	(0.56)	(5.12)	(5.06)
Secondary town	-106.38***	-93.91***	-12.93***	-16.25***	-130.68***	-96.52***	-376.35***	-245.07**
	(18.33)	(17.03)	(3.12)	(3.89)	(22.73)	(21.44)	(124.65)	(109.41)
Constant	7,219.89***	6,957.75***	48.53***	-100.61	474.60***	88.62	2,804.76***	-27,925.19***
	(48.73)	(177.33)	(11.69)	(285.46)	(49.12)	(1,499.49)	(347.61)	(10,067.60)
Prices	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Zone fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R-squared	0.244	0.288	0.197	0.305	0.302	0.435	0.215	0.286
Durbin (score) Chi^2	3.78*	8.63***	10.16***	17.02***	4.38**	16.62***	0.08	0.01
Wu-Hausman F test	3.77*	8.51***	10.22***	16.98***	4.37**	16.56***	0.08	0.01
Robust regression	2.01	4.91***	2.89*	4.32**	1.04	6.23**	0.02	0.00

Note: number of observations in each model is 720. For each variable, S1 refers to the first specification of the reduced form model and S2 refers to the second specification of the model with controls and prices (for the input regressions). The first panel reports the OLS estimates, while the second panel reports the Instrumental Variable regression ('2SLS') where transportation cost is instrumented by the natural path measure. The 'Durbin', 'Wu-Hausman' and 'Robust regression' test for endogeneity of transportation cost have H0: transportation cost is exogenous. Standard errors are clustered at village level and reported in parentheses below the coefficient: *** p<0.01, ** p<0.05, * p<0.1.

The second and third columns of Table 5.3 report the regression results of Equation 6 for the teff output price (natural logarithms, with the coefficients multiplied by 1,000 to ease interpretation). Both the reduced and full model in Table 6.3 indicate that teff prices are significantly lower for secondary farmers compared to Addis Ababa farmers. The price that secondary town farmers receive for their teff in the secondary city is estimated to be, on average, 8 to 10 percent lower compared to Addis Ababa farmers. The distance to the city that is the end destination of teff, has a significant and negative effect on the output price in all regressions.

The plot level usage of improved seed per hectare is shown to be significantly lower for secondary town farmers, compared to Addis Ababa farmers. All else equal, secondary town farmers use on average between 11 and 13 kg per hectare lower quantity of improved teff seeds. Distance to the city shows strong negative correlation to modern seed usage for both Addis Ababa and secondary town farmers. We also find that chemical fertilizer use is significantly lower for secondary town farmers. These farmers use between 86 and 127 kg per hectare less than Addis Ababa farmers. Hence, these secondary town farmers are much less likely to adopt modern inputs than are primate city farmers.

The last two columns of Table 5.3 report the estimation results for yields (kg/ha). In the reduced form specification, yields are, on average, notably lower for secondary town farmers. This effect is quite large at almost 400 kg per hectare, since the median yield in our dataset is 1,179 kg per hectare (see Table 4.2). This finding is confirmed by the results of the second model specification where we control for farm characteristics and prices, or when estimating the models with 2SLS to control for the endogenous location of roads. Moreover, the distance from the farm to the city where teff is sold is an important determinant of productivity. An increase in transportation cost of 10 ETB per quintal (which corresponds to an increase of 50 km – see Figure A.1 in Appendix II) reduces yields – all else equal – by almost 180 kg per hectare.

The results from the comparison of secondary town farmers with Addis Ababa farmers along several land intensification measures provide evidence that these outcomes, on average, are significantly lower for secondary town farmers. We find that the teff prices that farmers in the rural hinterlands of secondary towns receive are significantly lower, and these farmers are also less likely to apply modern inputs in their production of teff. As a consequence, we observe lower yields in the hinterlands of secondary towns compared to those in the hinterland of Addis Ababa. We find these effects in non-parametric and parsimonious regressions. The effect of the secondary town dummy remains significantly negative in the IV specification (where transportation costs are instrumented with the natural path) or in the second specification where we control for household characteristics and input and output prices in teff production, showing the robustness of our results to different specifications.

6. Conclusions

Given rapid urbanization in developing countries, there is an increasing interest in understanding the impact of the nature of urbanization on the economies of these countries. Secondary towns have been shown to lead to more inclusive growth and poverty reduction compared to primate cities. This is because rural migrants are more likely to participate in the non-farm sector of secondary towns (Christiaensen et al. 2016). However, less is known about how urbanization patterns affect agricultural production. In this study, we investigate this relationship between agriculture and different sized cities. A theoretical model shows that output prices and intensification decrease over distance (measured through transport costs) to a primate city, but that the presence of a secondary town introduces non-linearities in the relationship between these outcomes and urban proximity.

When we compare the model prediction with empirical observations, we find evidence that secondary towns influence the variation of teff prices when transportation costs to the primate city increase. The empirical section of this paper further tests how the size of the city and urban proximity affects agricultural intensification. When we compare intensification between farmers close to secondary towns and farmers close to Addis Ababa, we find that secondary town farmers use less modern inputs and achieve lower yields compared to their counterparts in the rural hinterland of Addis Ababa. Our results therefore show that the location of farmers with respect to cities and the type of cities have strong effects on farmers' intensification decisions in staple crop production.

Our findings have potentially important implications for a broader welfare perspective. Our conceptual analysis combined with the empirical results suggests that there may be a trade-off in terms of the impact of the nature of urbanization (one primate city versus multiple secondary towns) on agricultural development. The first effect is the positive influence from secondary towns. If secondary towns are absent in the rural economic space, and there is only the primate city where all urban consumers are located, our model predicts that at locations relatively remote from the primate city, it becomes unprofitable to produce agricultural outputs for the urban market. Hence, these farmers are excluded from the central market in the primate city and are most likely to remain subsistence-oriented farmers. In the case where the urban population is not concentrated in one primate city but partially distributed in secondary towns, the farmers who were initially located too far from the primate city to produce for its market are now influenced by the urban demand in the secondary towns. As a consequence, these farmers will start producing for these urban markets and become responsive to market signals from them. Moreover, improved access to modern inputs could allow them to intensify their agricultural production.[14] Hence, these non-linearities indicate that there is increased economic activity in the rural hinterlands because of the influence of secondary towns.

The second effect that we empirically observe in Ethiopia is that the impact of the secondary towns is smaller than that of the larger capital city. Hence, while more farmers may benefit from urban spillover effects on agricultural prices and access to modern inputs due to their proximity to secondary towns, the size of the benefits they realize may be smaller.

The trade-off (or the net effect) depends importantly on the relationship between the size of the cities and the variables that matter for farmers, such as agricultural prices and input markets. In terms of our conceptual model, the trade-off relates to the maximum value of the I-functions in the theoretical models (see Figures 3.2 and 3.3). The model that we have developed provides a framework to identify these welfare benefits and costs, and can thus guide us to calculate and measure these welfare trade-offs in future research, based on the type of empirical estimates that we have provided here.

[14] However, farmers that are located close to the primate city will be worse off when the population is scattered over several secondary towns, compared to the case when all consumers are concentrated in the primate city.

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8. Appendices

(c) Appendix 1 Sampling

We use data from a 2012 large-scale survey of teff producers located in five production zones around Addis Ababa – West Gojjam, East Gojjam, West Showa, South West Showa, and East Showa – which have the largest commercial surpluses of teff in Ethiopia. In total, 1,200 farmers were surveyed. These were representative of all teff farmers in the study zones. Farmers were randomly selected from both the smallest and largest teff producing woredas in these zones. To achieve this, all woredas were ranked in terms of cultivated area within a zone. Two woredas then were randomly selected from the top 50 percent and two from the bottom 50 percent producing woredas. Within each of the 20 selected woredas, all kebeles (villages) were ranked in terms of teff production. Two kebeles were randomly selected from the top 50 percent of teff-producing kebeles and one kebele from the bottom 50 percent. Hence, a total of 60 kebeles was randomly selected. Within each, a census was created that listed all farmers based on area cultivated. From this list, 20 farmers were randomly selected to be interviewed. Of these 20, ten farmers were selected from the list of large production farmers (cultivating all together 50 percent of the area) and ten farmers from small production farmers (the other 50 percent of the area).

(d) Appendix II: Calculation of transportation cost

We use detailed information on farmers' self-reported teff sales or barter transactions for teff harvested between September 2011 and August 2012 to identify the local trader market for each teff-selling farmer.[15] Farmers were asked what they considered the most common place of sale

[15] However, 145 farmers (i.e., 19 percent) did not record any teff transactions. For these farmers, we use data that was collected during a village level community questionnaire, as explained later.

during the last production season. 25 percent of farmers responded that they sold their teff in the village, and 75 percent responded that their teff was sold in a trader market where wholesalers were present. We know the name of the market (town) where the teff was sold for the latter group of farmers. For the farmers who sold teff in the village and for farmers without teff transaction information, we used community questionnaire information to identify the most common trader town used by teff farmers in each village. From a list of all markets visited by farm households within the village, we used different information (e.g., the size of the market and the share of teff traders in each market) to identify the most common teff trader town for each village.[16]

For the second leg of the teff transport (the first leg is from village to market), the teff is shipped from the trader market to a large wholesale market. For each farmer, we use the city that was identified in Section 4 to be the most likely end destination for the teff they produced.

To calculate the cost associated with the teff transport transaction, we need to reconstruct (i) the farm to 'trader market' trip and (ii) the 'trader market' to 'regional market' trip and measure the associated costs. The cost of the first trip was collected from the transaction level information. Farmers were asked to report the total cost (ETB) spent on transport for each transaction of teff output (quintal). As donkeys are the most common mode to transport teff to the trader town, this can be considered as a 'donkey cost'. The transport cost of the donkey trip was calculated from the total cost spent by the farmer to travel from the farm to the self-reported place of sales for each teff transaction. This cost was divided by the total amount of teff sold to get the per unit transport cost (ETB per quintal). This cost depends on the characteristics of the teff transaction. The self-reported

[16] For the farmers that sold teff in a trader market, these data can be compared with the self-reported market data from the farmer. For the majority of the farmers, these markets are the same, but some farmers participate in markets other than the most common village market.

cost could potentially be related to these characteristics or other factors. To avoid any endogeneity issues, we regressed the transportation cost (ETB per quintal) on the mode of transportation, the place of sale, and travel time to the place of sale; and subsequently use the predicted values. As most households performed multiple transactions, this was estimated using a fixed effects model. For those households that did not report any transactions, we used the village level data to replace the missing values.

As the teff is shipped from a trader town to a city by motorized trucks, we used ArcGIS software to calculate the transport cost using the road network in Ethiopia. The Network Analysis toolset was used to calculate the 'truck cost' for the second trip. A vector layer of the road network of Ethiopia was obtained from the WorldMap database (Guan et al. 2012).[17] For each road segment, the total length and the road quality is known.[18] To construct a transport cost measure, we need data on transportation cost for each segment, which is not available. We overcome this limitation by calculating a per distance (km) cost of shipping teff over each road segment in the following way. First, data on transportation costs incurred by teff traders for teff transportation with trucks were collected during complementary surveys to this survey. This transportation cost data is the total cost that traders and truckers in different trader markets faced when shipping teff to Addis Ababa using trucks. Moreover, during the community questionnaire, respondents were asked how much they thought it would cost to ship teff from the village center to Addis Ababa.[19]

[17] Map obtained from https://worldmap.harvard.edu/data/geonode:roads_jgy

[18] Based on the road quality, the following travelling speeds are assigned to each road class: Motorable tracks (35 km per hour), dry weather roads (45 km per hour), gravel all weather roads (60 km per hour), and asphalt all weather road (70 km per hour). This enables calculation of travel time between the trader towns and each end destination.

[19] Clearly, the main limitation of this data is that it only considers transport to Addis Ababa and no other cities. However, as the road network in Ethiopia is sparse, many of the routes from markets to Addis Ababa overlap with the routes to other cities. Only for the roads around the more remotely located villages, might there be data missing to ship teff to another city. These missing values were replaced by the average cost per road class per zone.

Using the ArcGIS Network Analysis tool, we reconstructed the routes that these truckers and traders used from the market place they serve to Addis Ababa, following the digitalized roads in the Ethiopian road network. For each route, we measured the travel distance using the 'Nearest Facility' toolbox, which allows us to calculate a transport cost per unit of distance for each route. These routes were then overlaid with the road network to assign a per distance transport cost for each road segment. Many of these routes overlap, implying that for each road segment we have different observations of transport cost. The average cost over different routes was calculated and used for each road segment. Finally, using the 'Origin Destination' toolbox in ArcGIS we calculated a distance, travel time, and transportation cost matrix for each pair of trader market – end destination routes, i.e., Addis Ababa or the secondary town.

The natural path distance is calculated in line with Damania et al. (2016) and Faber (2014). Using the Digital Elevation Model of Ethiopia, we first calculated a raster file with slope gradients. Then, we constructed a walking path friction surface raster file by calculating for each pixel the estimated time to cross the pixel on foot. Following Damania et al. (2016), we used the hiking velocity function proposed by Tobler (1993) to calculate the hiking velocity (V in km per hour) based on the slope (S in gradients) of the terrain: $V = 6 * e^{-3.5*|S+0.05|}$.

A new raster file is created which calculates for every pixel the 'cost' (i.e. time) it takes to cross the pixel following the velocity function of Tobler (1993). Then, for each city, we calculated the accumulated cost for each pixel to walk on foot to the city using the 'Cost Distance' tool in ArcGIS software. This approach can be extended, similar to the study undertaken by Schmidt and Kedir (2009), to take into account that it is impossible or more costly to cross rivers and lakes. These cost layers were then overlaid with the location of farmers, so that for each farmer (pixel) we know the walking distance to each city. Additionally, we computed least cost paths using the

‘Cost Path’ tool in ArcGIS software, which visually shows the least costly walking route for each farmer (which can then be compared with the actual road placement).

Figure A.1 below compares the different measures of distance. The transportation cost (ETB per quintal) measured as the combination of the ‘donkey’ and ‘truck’ cost, and the natural path distance (hours) are plotted against the physical distance from the farm to the end destination of teff. We see that our measure of transportation cost and natural path have a similar correlation with actual distance.

Figure A.1: Comparison of distance to market city measures—total transportation cost (sum of ‘donkey’ and ‘truck’ costs) in ETB per quintal (full line) and natural path cost in hours of travel time (dashed line)